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THE DESIGN OF EMPLACEMENTS FOR ROCKET MOTOR TESTING

by

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SUMMARY

This note outlines the consideration given by the combined M.O.W./M.O.S. Emplacements Working Party to the problem of designing emplacements for the firing of liquid propellant rocket motors.

It indicates proposals for a test-bed in which the operation of an 8000 lb thrust motor running continuously for periods of five minutes can be tested.

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1 Introduction

Following the serious explosion in one of the rocket test-beds at Westcott, a combined M.O.W./M.O.S. Working Party was set up to review the rocket motor test-bed design requirements, and to prepare specifications for new emplacements. The Working Party consists of representatives of the Ministry of Works (Architects and Engineering Divisions) and the Ministry of Supply (Armaments Research Establishment and Royal Aircraft Establishment).

One of the requirements was for emplacements capable of testing rocket motors of thrusts and durations likely to be demanded for aircraft propulsion. Considerable thought was given to the matter, and many ideas were put forward before the final design was agreed. The deliberations of the Working Party are recorded in the minutes of its meetings[1], but this note has been prepared for the convenience of those interested in test-bed design.

2 Emplacement requirements

The use of confined firing bays for the testing of rocket motors is necessary for two main reasons. The first is to economize in space, and the second to observe at close range either directly or indirectly the component under test. The alternative to firing in an emplacement is to fire in the open with the observation and control points at some distance from the test. Whilst it is necessary that certain large scale testing, for example the static firing of complete rocket missiles, should be done in dispersed emplacements, the amount of available space at Westcott makes it essential that smaller scale testing is done in relatively confined emplacements.

The emplacements under consideration in this note are required for testing a rocket motor which develops 8000 lb thrust over a maximum running time of five minutes. The corresponding total mass flow-rate of oxidant and fuel required is approximately 40 lb/sec. In addition to the firing chamber tank bays for the storage of up to 11,000 lb of oxidant and 3500 lb of fuel are included.

A further requirement of the design is that an explosion inside the firing chamber equivalent in power to 50 lb, of torpex should cause only repairable damage to the emplacement, and obviously the observing and control personnel should be completely protected. As a further safeguard the structure should afford to people in the control and observation rooms complete protection against an explosion in the firing bay equivalent to 150 lb of torpex.

The amount of torpex sufficient to produce the limiting amount of damage that can be repaired, in this case 50 lb, has been defined as the explosive limit of the emplacement. In computing the explosive limit an assessment is made of the total weight of fuel and oxidant that could be in the firing bay at any one instant. A figure in excess of this is taken and the worst conditions are assumed i.e. that the combustion chamber is half full of mixed fuel and oxidant, and that the pipe runs and pumps are full. It was intended in the early stages of the design that the explosive limit should be 35 lb of torpex. A later assessment of the whole problem indicated that a higher explosive limit could be tolerated from the point of view of design, and hence the figure was raised to 50 lb of torpex.

The chief problem in designing emplacements of this type is that of ensuring that a closed or semi-closed structure will withstand explosions of 50 lb of torpex. Little data on the problem exist, hence

the Working Party suggested that trials should be undertaken to obtain information on the best method of containing the blast impulses caused by explosions. These trials have been carried out at Thurleigh in Bedfordshire under the supervision of the Ministry of Works, but a full report on the results has not been received up to the time of writing. A preliminary assessment, however, has been made and this is given in a later paragraph dealing with the final design.

3 Shortcomings of existing Class A Emplacements

The original Westcott emplacements, designated Class A, were intended for testing motors of between 2000 and 3000 lb thrust only. Firings in these emplacements have shown up a number of defects in design.

A general lay-out plan of a Class A emplacement appears as fig.1. Prior to the explosion of 14th November, 1947, windows of armoured glass were fitted in the walls between the control room and the firing bay, and it was the frames of these windows that were the main cause of the casualties. Subsequent to the accident the window ports of the emplacements were covered with armoured steel plate, and observations of the motor under test are now made indirectly by mirrors.

Apart from this defect, the Class A emplacement has other drawbacks which make this type unsuitable for testing motors of the thrust envisaged. It is difficult in the first place to assess accurately the explosive limit of the emplacement. This has been fixed by the R.P.D. Safety Committee at 20 lb of torpex, but the figure can only be taken as the limit for protection to personnel. No accurate assessment can be made of the structural damage that would occur as a result of an explosion of this magnitude. The latest information seems to indicate that 20 lb of torpex is rather a high figure, and the subject is being further considered by the Safety Committee.

It was also felt that the housing of fuel and oxidant tanks in the same storage bay, as was envisaged in the original design of these emplacements, is undesirable. The feeding of the fuel and oxidant to the motor under test is often carried out by pressurizing the tanks with compressed gas. Under these conditions there is a danger of bursting one or both of the tanks and consequent mixing of fuel and oxidant. This danger is accentuated by the present necessity for using light alloy tanks tested up to a pressure, the ratio of which to the working pressure is of the order of 1.5, which is less than that demanded for new tanks specially designed for the purpose. To overcome this disadvantage in design it has been laid down that in the two Class A emplacements at present in use one rear storage bay shall house the oxidant for both firing chambers and the other the fuel for both chambers. It is not necessary that the same fuels or the same oxidants are stored in the respective bays.

4 Basis of design

The size and strength of an emplacement is chiefly governed by the thrust of the motor to be tested in it. On this factor depend the strength of the structure to which the motor is fixed and the explosive limit of the emplacement which is governed, as explained before, by the size of the combustion chamber. The upper limit for the aircraft emplacements was set at 8000 lb thrust with a maximum non-stop running time of five minutes. This latter factor is important, of course, in determining the size of fuel and oxidant bays needed to accommodate the quantities required, but bears no relation to the strength and size of the firing chamber itself.

An important requirement in the design is effective observation of the motor under test. Though direct observation is probably the most satisfactory, from the point of view of the officer controlling the test, it has been completely ruled out by the Working Party in their consideration of design. Various methods of indirect observation have been considered[2], and detailed design work on the more promising is in hand.

Apart from the testing of motors of bigger thrust and longer running times, other requirements of the aircraft emplacements are similar to those provided for the Class A emplacements. For example, holes have to be provided in the wall between the firing bay and the control room for the valve systems, which operate the motor, and for other devices.

5 Early design considerations

It was realised from the first that the chief difficulty in preparing a design of an emplacement with an explosive limit of the order of 50 lb of torpex lay in the lack of available data for enabling blast impulses resulting from an explosion to be expressed as an equivalent steady static loading on which wall thickness, amount of buttressing, etc., could be based. First consideration was given to a rectangular structure, similar to the Class A emplacements, with a roof of approximately the same strength as the walls. This type of construction would tend to enclose any explosion and hence reduce the surrounding danger zone to a minimum, as risks from falling fragments would be obviated to a large extent. It was suggested that such emplacements might be built as single units with the observation room along one side and the fuel and oxidant bay adjacent to the opposite side. This would avoid the necessity for housing the fuel and oxidant at the rear (i.e. on the closed side) of the emplacement, and give greater freedom of access and at the same time reduction in danger area to the rear. It was realised that one of the bad features was the proximity of the fuel and oxidant storage bays. It was taken as a principle in the design that the danger from blast or fragments should be restricted to one general direction only, that is along the axis and on the open side of the emplacement.

It soon became apparent that as a result of the lack of information on the correlation between blast impulse figures and steady static loading, the design of a rectangular structure to withstand a certain explosive limit was going to be a difficult task. It was at this stage that the Ministry of Works representatives suggested that the emplacement might consist of a steel cylinder backed on the outside with concrete. The blast impulse would then be taken in ring tension and it would be possible, by means of scale experiments, to obtain information on what such structures could withstand.

6 Development of cylindrical emplacement design

After it had been agreed that a cylindrical firing chamber offered the best solution, two emplacement designs were considered. In both designs one end of the emplacement was closed; in the first by a vertical wall buttressed on the outside; in the second by a hemispherical closure. In both cases the oxidant and fuel bays were on one side of the firing bay and the control room was on the opposite side. The control room was to be semi-sunken so that the periscopes to be used for indirect observation could be set in the roof. Consideration at this stage was given to the possibility of separating the fuel and oxidant bays. The ideal method would be to build them on either side of the emplacement, but then the control room would have to be at the rear. The obvious difficulties of observing the motor under test with this arrangement led to the rejection of this idea.

Up to this point in the discussion of the design only emplacements built in single units had been considered. It had been argued that firing in single emplacements would cause the least inconvenience to work being carried out in other firing bays, but that the idea of twin emplacements need not be rejected if other factors pointed in their favour. It was thought that the possibility of using a common observation and control room for two emplacements set at right angles might be a factor in favour of building emplacements in pairs.

7 Development of twin emplacement design

As mentioned before, the guiding principle in the consideration of the design of these emplacements was the restriction of the danger from either the firing chamber itself or from the bursting of pressurized tanks to an area on the open side of the emplacement. Although the building of emplacements in pairs with the axes of the firing bays at right angles would increase the angle of the danger area, any considerable advantage in the scheme might offset this disadvantage.

Fig.2 shows the first design of this type with a common observation and control room and the respective fuel and oxidant bays on the opposite side of each emplacement. The scheme has the merit of economy in space, but subsequent examination showed that it would be very difficult to protect adequately the corner of the control room nearest to the firing bays.

A new factor in the development was introduced at this stage, that of having both ends of the firing chamber open to the atmosphere. It was necessary, however, in order to preserve the area to the rear of the emplacements free from danger to have very close to the rear end of the emplacement a high blast wall which would prevent the escape of fragments moving in any direction from the back of the firing bay. The A.R.E. representative on the Working Party stated that experience had shown that even a small venting area, as envisaged in this scheme, would materially reduce the damage caused by the initial blast impulse.

As explained above, this type of twin emplacement with the control room between the firing bays was rejected because of the large amount of protection required for the corner of the observation room. The next step was to consider a similar design with the firing chambers splayed outwards, and the fuel and oxidant bays arranged between them (fig.3). In this case the control rooms were arranged along the outside walls of the two emplacements, and thus were not exposed to danger, but closer study revealed that the fuel and oxidant bays, whose sizes were controlled by the geometry of the design, were not nearly large enough for the quantities of propellant envisaged.

To overcome this difficulty it was found necessary to revert to a design for twin emplacements with the axes of the firing chambers parallel to each other and also parallel to the axes of the four exidant and fuel bays (fig.4). Thus it became apparent at this stage that little advantage would accrue from building double emplacements. A further disadvantage in this particular design lay in the long pipe runs that would be required from the outside fuel bay to the firing chamber. These supply lines should be kept as short as possible, chiefly to prevent excessive pressure drops along them; it will be noticed that this requirement had been met in all previous designs. There is also, of course, the overall difficulty with a twin emplacement design that firings in one bay may quite likely interfere with the progress of work in the other; this factor would not apply with such great effect in single emplacements.

After an exhaustive study of the advantages and disadvantages of twin emplacements it was decided to revert to single emplacements.

8 Development of the final emplacement design

The proposed final design of the aircraft emplacements is shown in fig.5. Consequent upon the requirements that there should be an increase in explosive limit from 35 lb to 50 lb of torpex and that control personnel should be adequately protected from an explosion up to 150 lb of torpex, it was decided at this stage to build the firing chamber as two concentric steel tubes with the space between them filled with concrete. In order to cushion the effect of an explosion the firing chamber and observation room are shown built on independent foundations with an air space between those portions that lie above ground.

The trials at Thurleigh, mentioned in a previous paragraph, indicate that there is a safety factor of at least five for an explosion of 150 lb of torpex in such an emplacement which will also be able to withstand between 200 and 300 explosions of 50 lb of torpex without serious structural damage.

After discussing the detailed requirements, the Working Party drew up a specification as a basis for working drawings. Some extracts from the specification are given below:-

(a) The firing bay will consist of concentric steel tubes loaded with concrete of a mixture as laid down by M.O.W. Structural Engineers, the internal tube being approximately 15 feet inside diameter by 23 feet 6 inches long.

(b) The rear end of the firing tube to be open-ended, with traverse of earth to withstand face-on blast specified, and spaced approximately four feet distant from it. The traverse to be faced with sleepers or similar material to prevent ricochet.

(c) Observation of the rocket motors in the firing bay will be by means of periscopes fitted by such a method that no direct blast in the event of an explosion passes to the control room via the periscope tubes. Periscopic observation is required to cover the full length of the firing tube plus three feet outside the tube at the firing end. In order that two observers can view the firing simultaneously the last seven feet of the chamber will have duplicate observation.

(d) The inside of the firing tube, the end doors and all steel pipe work to be protected from the corrosive effect of weak acid by spraying or painting with suitable acid-proof paint.

9 Conclusions

After considering all aspects of the problems involved in designing emplacements for the testing of rocket motors in confined spaces, the Emplacements Working Party decided, in accordance with the small amount of data available, that a cylindrical firing bay offered the best solution against damage from accidental explosions.

It was decided to vent such a cylindrical firing bay at both ends, but with a high blast wall erected close to the opening at the rear. By this means the danger from blast and fragments, in the event of an explosion, would be confined to the general area adjacent to the open side of the emplacement.

REFERENCES

No.	Author	Title, etc.
1		Minutes of the Emplacements Working Party, copies of which may be obtained from the author.
2	H.R. Noble	Indirect Methods of Observation Technical Note No. R.P.D.15.

Attached:-

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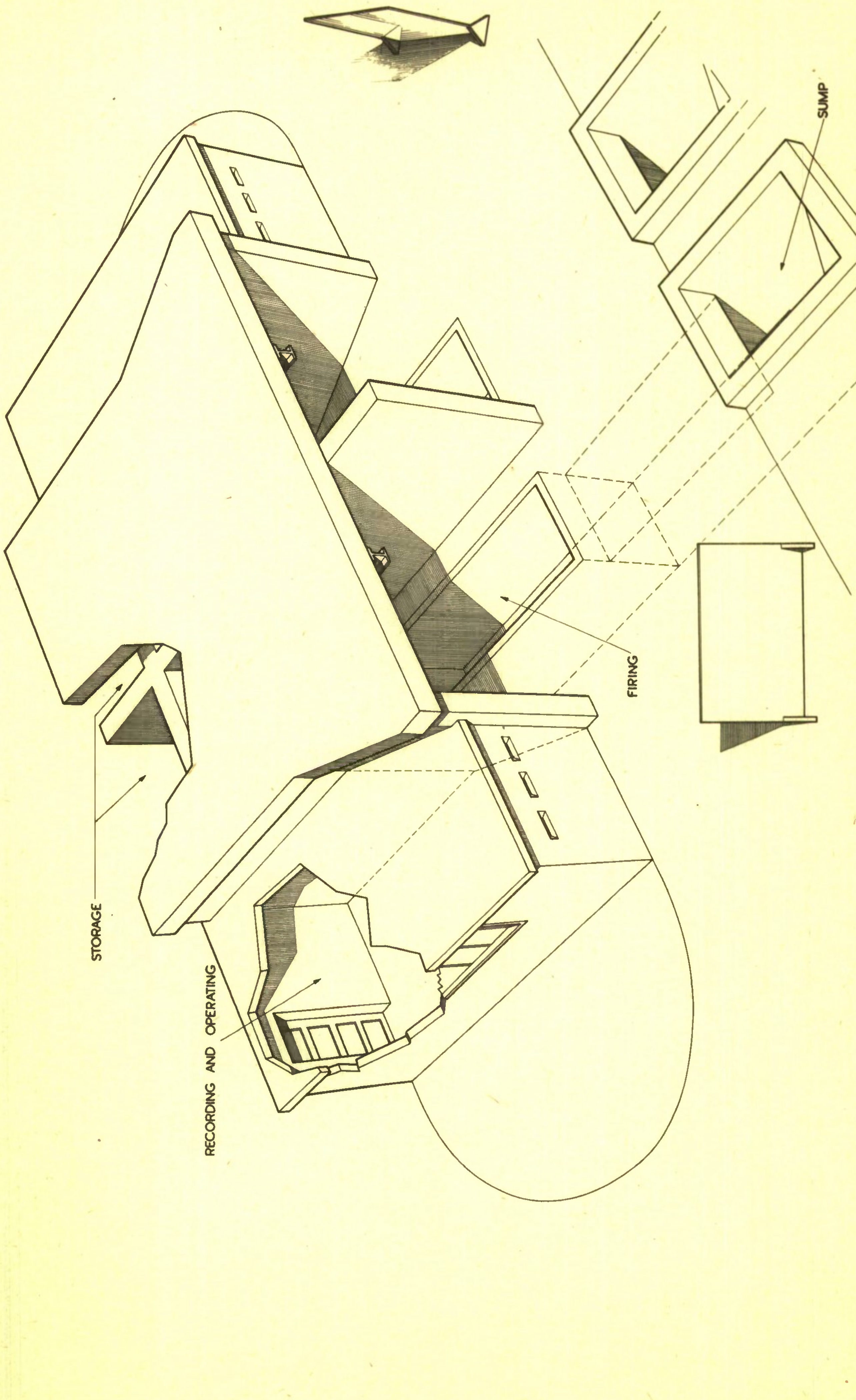

FIG.1. CLASS 'A' EMPLACEMENTS

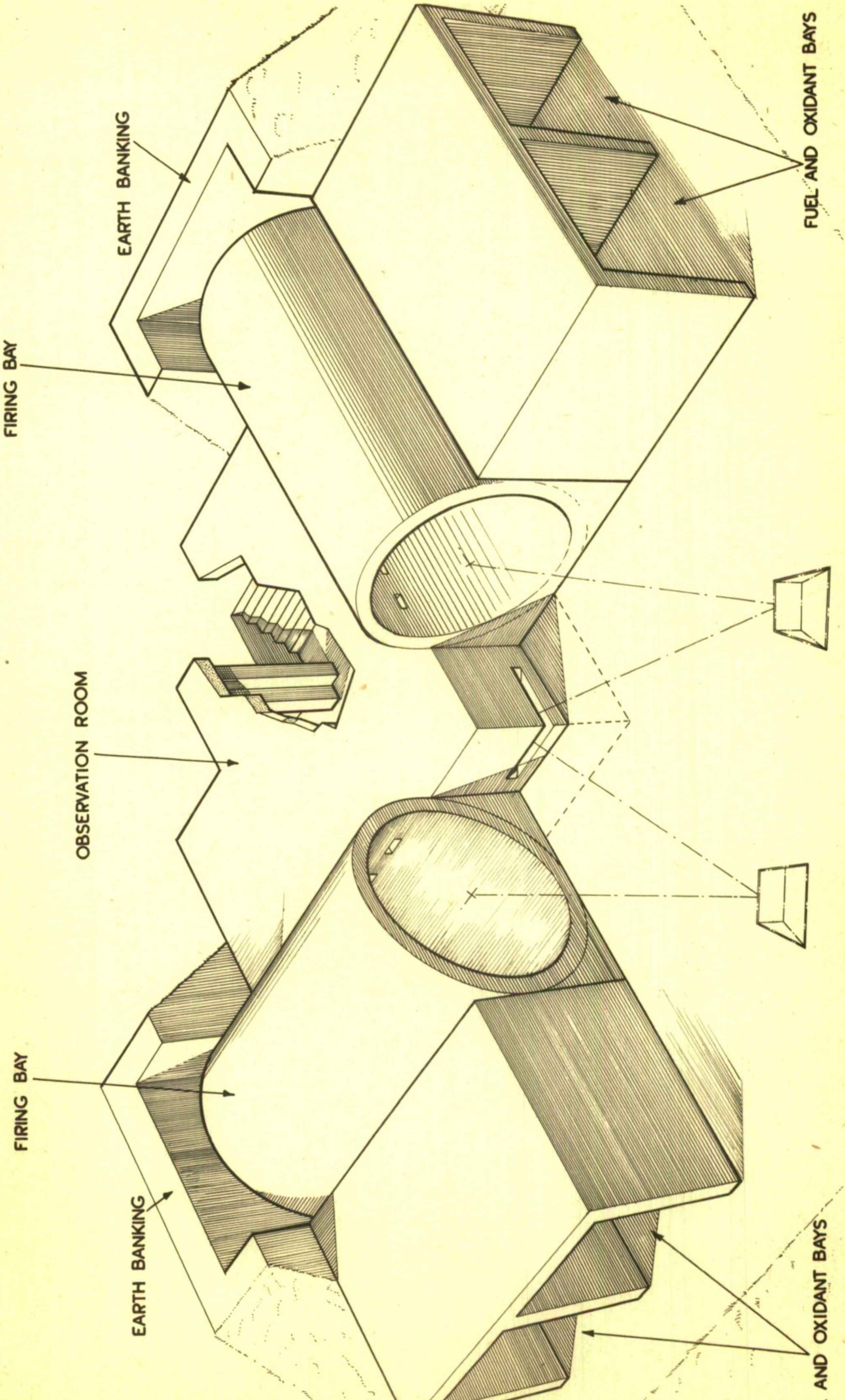

FIG.2. FIRST DESIGN OF TWIN EMPLACEMENT

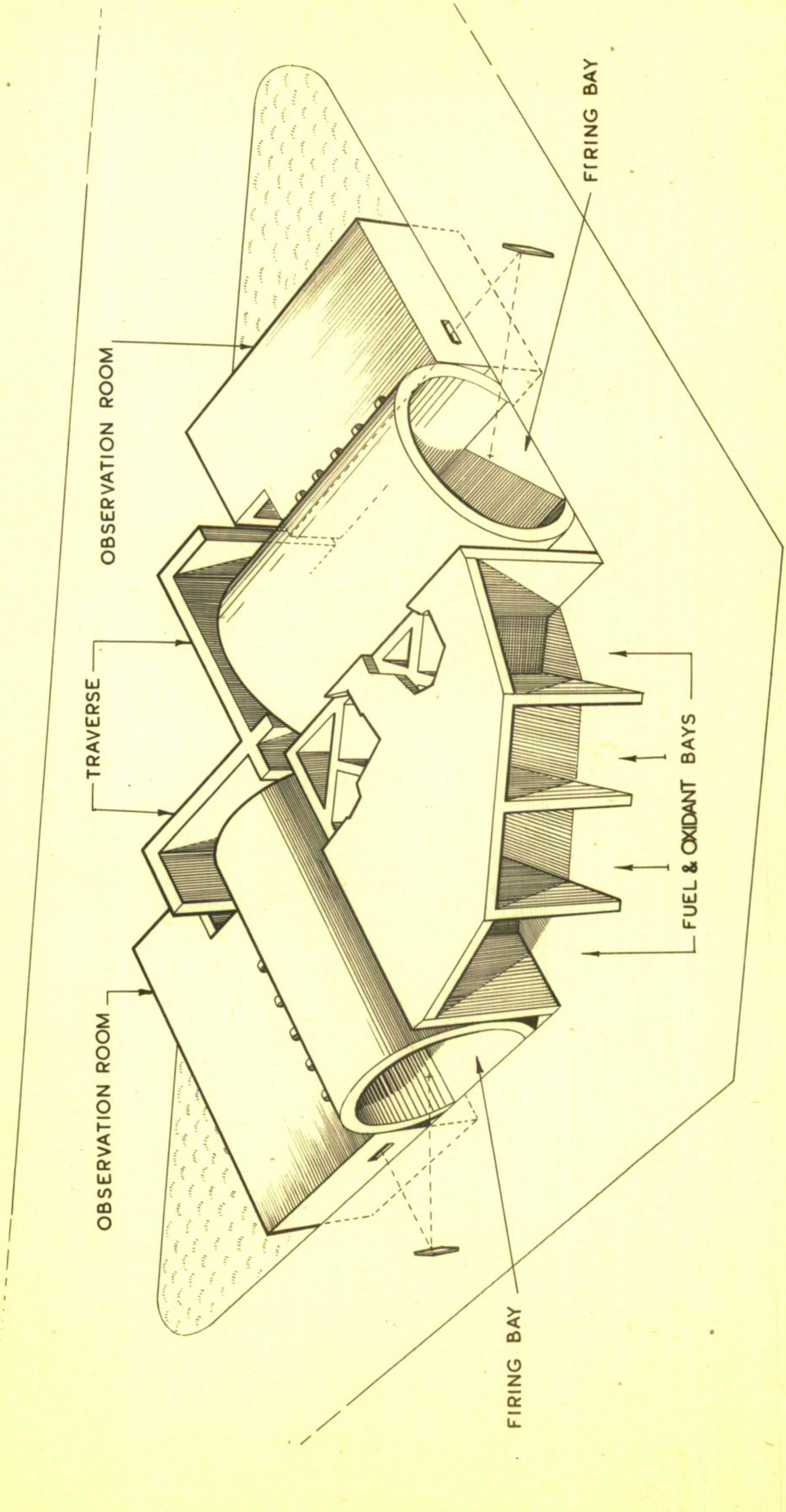

FIG.3. SECOND DESIGN OF TWIN EMPLACEMENT

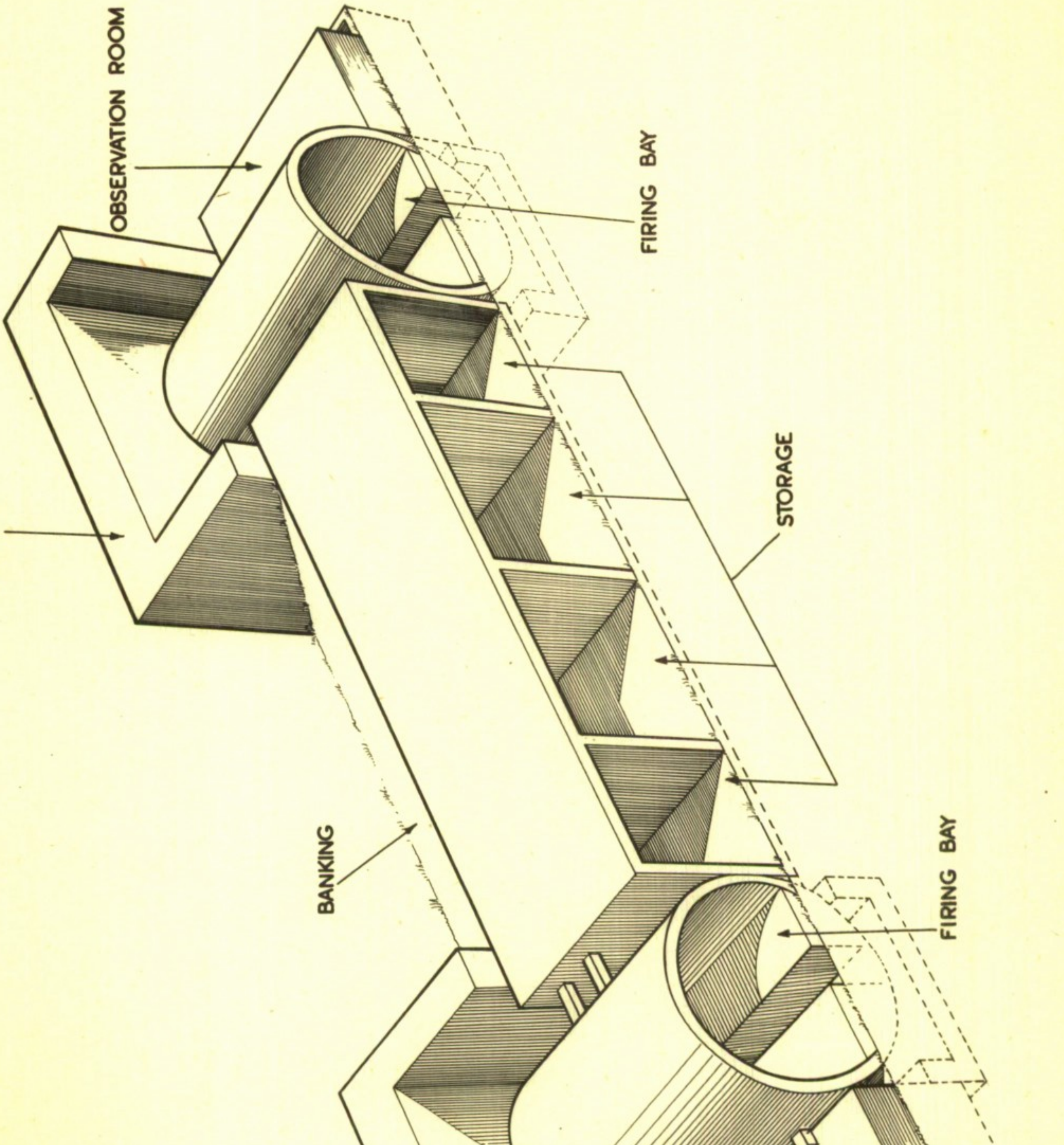

FIG.4. THIRD DESIGN OF TWIN EMPLACEMENT

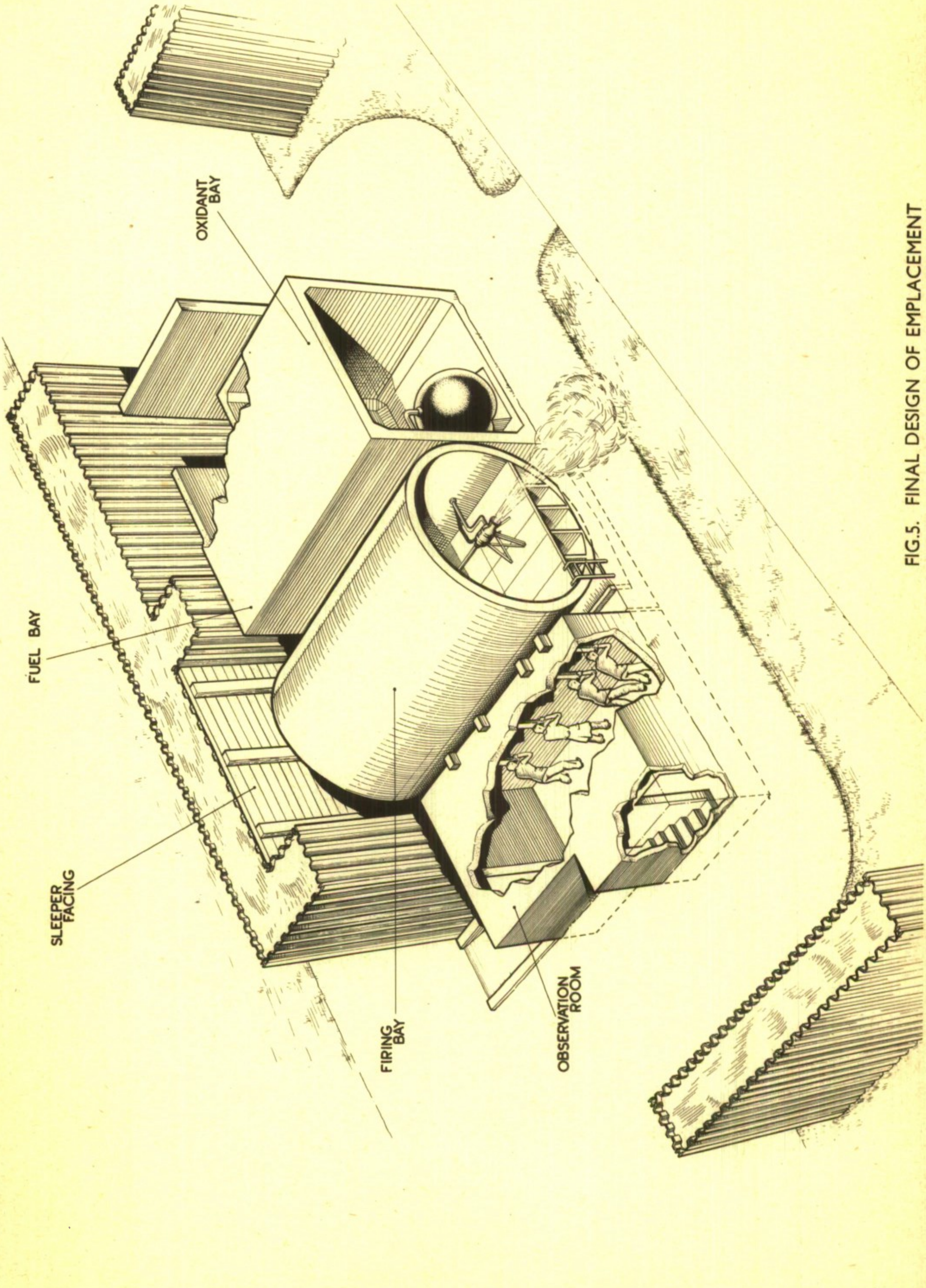

FIG.5. FINAL DESIGN OF EMPLACEMENT

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